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January 12, 1995

Mr. William F. Caton
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Dear Mr. Caton:

As requested by the Common Carrier Bureau Tariff Division, attached is a copy of the Christensen Associates paper "Total Productivity in the Bell System" released in September 1981.

An original and two copies of this ex parte notice and attachment are being filed in the Office of the Secretary on January 12, 1995. Please include this notice and attached material in the public record of these proceedings.

Respectfully submitted,

Frank McKennedy
Director - Policy Analysis

Attachment

cc:    Mark Uretsky
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Economic Analysis and Consulting

# TOTAL FACTOR PRODUCTIVITY IN THE BELL SYSTEM

by

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## 1. INTRODUCTION

The purpose of this paper is to provide an intertemporal comparison of total factor productivity (TFP) for the Bell System in the production of telecommunications services.[1] TFP indicates the overall level of efficiency that is achieved by a firm in transforming resources (labor, capital, and materials) into goods and services.[2] We use the index number approach to estimate the year-by-year rate of change in TFP by the Bell System over the period 1947-79.

The measurement of TFP requires a detailed set of accounts, separating the value of each input and output into its quantity and price components. In Section 2 we describe the index number procedures employed to separate output and factor input in current prices into price and quantity components. We also define TFP in terms of these index numbers and specify measures of real labor, capital, and materials inputs and measures that reflect changes in the composition of labor and capital. In Sections 3, 4, 5, and 6, we present the data and procedures used to construct input and output quantities and prices. In Section 7 we show the resulting total input, total output and TFP indexes.

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[1] For this study we define the Bell System to include AT&T Co., AT&T Long Lines, and all Bell Operating companies in which AT&T Co. has controlling interest.

[2] Fabricant (1974) provides an overview of productivity measurement.

## 2. METHODOLOGY

2.1  Introduction.  In this section we present our methodology for constructing

an index of TFP.  The conventional approach to the measurement of TFP involves the

computation of an index of real output and an index of real factor input.  TFP is

defined as the ratio of the real output to real factor input.  Alternative

approaches differ substantially in the choice of procedures for obtaining indexes

of aggregate output and input.

2.2.  Theory of Index Numbers.  The traditional method for aggregating

individual outputs and inputs is to use the Laspeyres index.  The Laspeyres index

can be written as

$$(1) \qquad X_1/X_0 = \Sigma \ P_{i0}X_{i1}/\Sigma \ P_{i0}X_{i0} = \Sigma w_{i0}(X_{i1}/X_{i0})$$

where $w_{i0} = P_{i0}X_{i0}/\Sigma \ P_{i0}X_{i0}$, the subscript zero is the base period, and the

subscript one is the comparison period.  The widespread use of the Laspeyres index

evidently stems from its ease of use and intuitively appealing interpretation.

Since prices are being held fixed at their base period levels, the Laspeyres index

purports to show how much of the change in value of total input results from changes

in quantity.

An alternative approach widely used in current empirical research is the

(arithmetic average) weighted log-change index

$$(2) \qquad \ell n \ (X_1/X_0) = \Sigma \ \bar{w}_i \ \ell n \ (X_{i1}/X_{i0})$$

where $\bar{w} = (w_{i1} + w_{i0})/2$.  This index is one of many mentioned in passing by

Fisher (1922).  It has been recommended for applications by Tornqvist (1936) and

subsequently by Theil (1965) and Kloek (1966). It has been used by Christensen
and Jorgenson (1969, 1970, 1973a, 1973b) to implement a complete system of national
accounts in current and constant prices. In this paper we refer to this index
number procedure as the Tornqvist index. A convenient feature of the Tornqvist
index is that for time series data the log-changes can be interpreted as rates of
growth, since:

$$\dot{X}/X = d \ln X/d t \quad \simeq \Delta \ln X_t = \ln (X_t/X_{t-1})$$

The economic theory of exact index numbers can be described as rationalizing
index number formulas by particular functional forms for production functions.
Recent contributions to this theory have been made by Afriat (1972), Diewert (1976),
Pollak (1971) and Samuelson and Swamy (1974). Index number formulas have long been
thought of as approximating production functions. Results are now available
showing that index number formulas represent exactly particular production functions.
The production functions underlying both the Laspeyres Index and the Tornqvist Index
have been discovered.

The Laspeyres Index is exact for a linear production function, which specifies
a priori that all factors are perfect substitutes in the production process. The
Tornqvist Index is exact for the homogeneous translog production function proposed
by Christensen, Jorgenson, and Lau (1971, 1973). The homogeneous translog production
function can provide a second order approximation to an arbitrary twice-differen-
tiable homogeneous production function. Diewert (1976) has used the term
"superlative" to characterize index numbers which are exact for production functions
having this approximation feature. Such production functions are often referred to
as "flexible" because they can approximate production structures with arbitrary
substitution possibilites.

A fundamental result of the economic theory of production is that producers minimize costs of production by using all inputs in proportions such that their marginal productivities are equal to their purchase prices. The indexes we have been discussing can be interpreted as using prices or marginal productivities to weight input quantities. The basic difference between the Laspeyres and the Tornqvist (and other superlative) Indexes is that the Laspeyres Index holds prices fixed at their base period levels while the Tornqvist Index uses the prices from both the base period and the comparison period.

The use of fixed base period prices in the Laspeyres Index can be interpreted in terms of the linear production function. If there is perfect substitutibility among factors of production, then an increase in the relative price of any one input would cause discontinuation of its use. If a perfect substitute is available at a lower price, there is no rationale for using the higher priced input. If all inputs are used in both the base period and the comparison period, it follows that the relative prices are the same in both periods. There is no need to consider the comparison period prices since they are unchanged from the base period.

The translog function does not require inputs to be perfect substitutes. If the relative price of an input increases, the producer decreases its use (substituting other inputs) until all marginal productivities are proportional to the new prices. Hence, the prices from both periods enter the Tornqvist Index to represent the marginal productivities in both periods. Diewert (1976) has also discussed other members of the class of superlative indexes. This class includes the geometric mean of the Laspeyres and Paasche indexes. This procedure was advocated by Fisher (1922), and has since been known as the Fisher Ideal index.

Ruggles (1967) used data from 19 Latin American countries to compare the results of using several indexes including the Laspeyres, Paasche, Fisher Ideal and Tornqvist

indexes. He found that the Laspeyres and Paasche indexes differed radically from each other and substantially from the Tornqvist and Fisher Ideal indexes. However, the Tornqvist and Fisher Ideal indexes were virtually identical. This provides evidence that it can be important to use a superlative index but that the choice among superlative indexes is of much less importance. Following Christensen and Jorgenson (1973a), we adopt the Tornqvist index for all results reported below.

   2.3.  Real output and real factor input.  Total factor productivity uses an index of real product. Denoting the index by Y, we express the fuctional relationship between aggregate output and its components as

(3) $$Y = f_y(Y_1, Y_2, \ldots, Y_n)$$

The homogeneous translog form of (3) can be expressed by the Tornqvist index

(4) $$\Delta \ln Y_t = \sum_{i=1}^{n} \bar{v}_{it} \, \Delta \ln Y_{it} \, ,$$

where $\bar{v}_{it}$ is the arithmetic mean value share (over periods t and t-1) of $Y_i$ in total product.

   Denoting the index of real factor input by Q, we express the functional relationship between Q and its components as

(5) $$Q = f_Q(L, K, M),$$

where L is an index of aggregate labor services, K is an index of aggregate capital services and M is an index of aggregate materials services. The labor, capital and materials indexes are themselves functionally related to their components

(6) $$K = f_K(K_1, K_2, \ldots, K_n).$$

(7) $\quad\quad\quad L = f_L(L_1, L_2, \ldots, L_p)$

(8) $\quad\quad\quad M = f_M(M_1, M_2, \ldots, M_m)$

where $L_i$ is the level of labor services provided by persons in the $i^{th}$ skill class, $K_i$ is the level of capital services provided by the capital stock of the $i^{th}$ asset class, and $M_i$ is the level of materials services provided by raw materials of the $i^{th}$ type.

Homogeneous translog forms of (5), (6), (7), (8) can be expressed by Tornqvist indexes

(9) $\quad\quad\quad \Delta \ln Q_t = \bar{w}_{Kt} \Delta\ln K_t + \bar{w}_{Lt} \Delta \ln L_t + \bar{w}_{Mt} \Delta \ln M_t,$

(10) $\quad\quad\quad \Delta \ln K_t = \sum_{i=1}^{n} \bar{w}_{Kit} \Delta \ln K_{it},$

(11) $\quad\quad\quad \Delta \ln L_t = \sum_{i=1}^{p} \bar{w}_{Lit} \Delta \ln L_{it},$

(12) $\quad\quad\quad \Delta \ln M_t = \sum_{i=1}^{m} \bar{w}_{Mit} \Delta \ln M_{it}$

where $\bar{w}_K$, $\bar{w}_L$ and $\bar{w}_M$ are the mean shares of capital, labor and materials services in the value of total input, $\bar{w}_{Ki}$ is the mean share of the $i^{th}$ type of capital service in the value of total capital input, $\bar{w}_{Li}$ is the mean value share of the $i^{th}$ type of labor service in the value of total labor input, $\bar{w}_{Mi}$ is the mean value share of the $i^{th}$ type of raw material in the value of total materials input.

There are special considerations which have to be made in measuring capital input. If all capital items were rented or leased, then the value of rent and lease payments would equal the value of capital input. However, for most business enterprises the vast bulk of capital goods are owned rather than leased. Therefore, the value of capital input must be inferred by constructing the annualized cost of

owning the various types of capital. We follow the methodology developed by Christensen and Jorgenson (1969) in constructing our capital accounts.

We assume that the flow of capital services from each type of asset is proportional to the stock of the asset at the end of the previous period (the beginning of the current period). We denote the factors of proportionality by $q_{Ki}$ and write

$$(13) \qquad K_{it} = q_{Ki} K^A_{i,t-1} \; ,$$

where $K^A_{i,t-1}$ is the stock of the $i\underline{th}$ asset type. Substituting (13) into (10) we have

$$(14) \qquad \Delta \ln K_t = \sum_{i=1}^{n} \bar{w}_{Kit} \, \Delta \ln K^A_{i,t-1}$$

since the $q_{Ki}$'s are constants. This shows that the rate of growth of aggregate capital services is a weighted average of the rates of growth of the various types of capital stock. It is incorrect, however, to interpret this as the rate of growth of aggregate capital stock because the weights are relative value shares in the total service flow rather than relative shares in the value of capital stock. This aggregate capital stock can be expressed as a Tornqvist index of its components

$$(15) \qquad \Delta \ln K^A_t = \sum_{i=1}^{n} \bar{w}_{Ait} \, \ln K^A_{it}$$

where $\bar{w}_{Ai}$ is the relative asset share of the $i\underline{th}$ asset class.

The capital service flow from each type of asset is proportional to the corresponding stock. Relations (14) and (15) reveal that the analogous relationship is not true for aggregate capital services. The ratio of aggregate capital services to aggregate capital stock is not constant. It depends on the composition of the aggregate stock. Therefore, it is incorrect to use the aggregate capital stock to

represent aggregate capital services. Let us denote the ratio of capital services to capital stock by $q_{Kt}$ which is potentially different for each time period. Thus $q_{Kt}$ is variable even though each $q_{Ki}$ is a constant. We can write

$$(16) \qquad K_t = q_{Kt} K_{t-1}^A$$

The index $q_{Kt}$ can be interpreted as the capacity of the aggregate capital stock to produce capital services. Since $q_{Kt}$ can be written as $K_t / K_{t-1}^A$, we see that it indicates the flow of capital services per unit of aggregate capital stock. Henceforth, when we use the term "composition index of capital," we will be referring to $q_{Kt}$.

Just as it is erroneous to use aggregate capital stock to represent aggregate capital services, it is also erroneous to use aggregate hours worked to represent aggregate labor services. Aggregate hours are computed simply by summing the number of manhours of each type. This means that each hour is given the same weight regardless of skill class. Thus we can write aggregate hours as

$$(17) \qquad \Delta \ln L_t^H = \Delta \ln \sum_{i=1}^{P} L_{it}^H \;.$$

We assume that the flow of capital services per hour is constant for each skill class

$$(18) \qquad L_{it} = q_{Li} L_{it}^H \;,$$

where $q_{Li}$ is the flow of labor services per hour worked by someone in the $i^{th}$ skill class.

The Tornqvist index of labor services can be written

$$(19) \qquad \Delta \ln L_t = \sum_{i=1}^{P} \bar{w}_{Lit} \, \Delta \ln L_{it}^H$$

where $\bar{w}_{Lit}$ is the mean share in labor compensation of the $i^{th}$ skill class of hours worked. We define the "composition index of labor" ($q_{Lt}$) as the flow of aggregate labor services per manhour $L_t/L_t^H$. Thus we can write

$$(20) \qquad L_t = q_{Lt} L_t^H$$

where

$$(21) \qquad \Delta \ln q_{Lt} = \sum_{i=1}^{P} \bar{w}_{Lit} \, \Delta \ln L_{it}^H - \Delta \ln \sum_{i=1}^{P} L_{it}^H \; .$$

The possible interpretations of $q_{Lt}$ are exactly analogous to those of $q_{Kt}$. It represents the error involved in using aggregate hours as the measure of total labor input.

2.4. **Productivity.** Substituting (16) and (20) into (9) we have

$$(22) \qquad \Delta \ln Q_t = \bar{w}_{Kt} \, \Delta \ln K_{t-1}^A + \bar{w}_{Kt} \, \Delta \ln q_{Kt} + \bar{w}_{Lt} \, \Delta \ln L_t^H$$
$$+ \bar{w}_{Lt} \, \Delta \ln q_{Lt} + \bar{w}_{Mt} \, \Delta \ln M_t$$

Thus the rate of growth of total factor input is composed of five appropriately weighted components: (a) the rate of growth of capital stock; (b) the rate of growth of the composition index of capital; (c) the rate of growth of total hours; (d) the rate of growth of the composition index of labor, and (e) the rate of growth of materials. Combining (22) with the definition of total factor productivity ($A = Y/Q$) we can write

$$(23) \qquad \Delta \ln A_t = \Delta \ln Y_t - (\bar{w}_{Kt} \, \Delta \ln K_{t-1}^A + \bar{w}_{Kt} \, \Delta \ln q_{Kt}$$
$$+ \bar{w}_{Lt} \, \Delta \ln L_t^H + \bar{w}_{Lt} \, \Delta \ln q_{Lt} + \bar{w}_{Mt} \, \Delta \ln M_t)$$

### 3.  MEASUREMENT OF OUTPUT

The starting point for the construction of an index of real product is the measurement of the value of total product in current prices.  Our concept of output is intermediate between gross output at market prices and gross output at factor cost, as these terms are usually employed.  We exclude indirect business taxes unrelated to factor outlay, such as retail sales taxes and excise taxes. However, indirect business taxes which are part of the outlay on factor services, such as property taxes, are retained in our gross product measure.[3]

To construct our output measure we start with the value of operating revenues broken down into various categories.  The categories used are:

1)  Local revenues

2)  Toll - interstate revenues

3)  Toll - intrastate revenues

4)  Directory advertising revenues

5)  Miscellaneous revenues

Data for these five revenue categories are presented in Table 1.  They are net of sales and excise taxes.  However, they include gross receipts taxes, which are indirect business taxes not related to factor input.  Furthermore, uncollectible revenues are included in the five categories.  It is necessary to subtract gross receipts taxes and uncollectible revenues to arrive at revenues from the producer point of view.  Data on uncollectible revenues by output type are not available. We believe the most reasonable assumption is that uncollectible revenues occur proportionately in the five revenue categories.  Therefore, we subtract

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[3]These classifications were proposed by Christensen and Jorgenson (1970)

uncollectible revenues and gross receipts taxes proportionately from the five revenue categories. Data for uncollectible revenues and gross receipts taxes are presented in Table 1. Total revenue net of gross receipts taxes and uncollectible revenues is also presented.

The next task is to separate the revenue categories into price and quantity components. We deflate each adjusted revenue category to arrive at real output. The deflators used are rate indexes which are described in detail in the Bell System Productivity Study, 1947-1971.[4] These are based to 1.0 in 1967 and hence outputs are expressed in 1967 dollars. Table 2 gives these five real outputs and their prices. These five outputs are then aggregated using the Tornqvist index procedure assuming the relative rate indexes are equal to the relative marginal costs of producing the outputs. Aggregate output and its deflator are presented in Table 3.

In Table 4 we present the shares of total revenue accounted for by each output in each year. In Table 5 we present the rate of growth of each output type and aggregate output in each year. Tables 4 and 5 also contain the average shares and growth rates over the full sample period 1947-1979 and the subperiods before and after 1961.

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[4]This document was prepared by the Economic Analysis Section of the Comptroller's Office, AT&T. Hereafter it is referred to as BSPS.

# Table 1

## Revenues, Gross Receipts Taxes and Uncollectible Revenues

### (millions of dollars)

| Year | Local | Toll: Interstate | Toll: Intrastate | Directory Advertising | Miscellaneous | Uncollectible Revenues | Gross Receipts Taxes | Total |
|---|---|---|---|---|---|---|---|---|
| 1947 | 1272.9 | 525.0 | 387.6 | 82.1 | 13.6 | 6.6 | 42.6 | 2232.0 |
| 1948 | 1506.3 | 570.7 | 430.1 | 101.1 | 16.1 | 8.4 | 46.6 | 2578.2 |
| 1949 | 1697.3 | 584.1 | 487.7 | 116.6 | 17.8 | 10.2 | 53.5 | 2839.7 |
| 1950 | 1941.4 | 663.5 | 521.2 | 125.7 | 19.3 | 9.5 | 61.3 | 3200.3 |
| 1951 | 2146.4 | 784.9 | 558.0 | 138.4 | 21.2 | 9.5 | 69.8 | 3569.7 |
| 1952 | 2397.6 | 874.5 | 595.8 | 159.9 | 23.0 | 11.1 | 76.5 | 3963.2 |
| 1953 | 2642.9 | 951.6 | 619.5 | 190.0 | 25.0 | 12.2 | 87.4 | 4329.3 |
| 1954 | 2837.0 | 1050.3 | 670.5 | 215.1 | 26.6 | 14.9 | 93.3 | 4691.2 |
| 1955 | 3086.5 | 1200.4 | 759.3 | 234.7 | 30.3 | 14.0 | 100.7 | 5196.3 |
| 1956 | 3368.6 | 1344.7 | 831.6 | 264.1 | 33.1 | 16.8 | 114.4 | 5710.9 |
| 1957 | 3647.6 | 1466.5 | 891.1 | 294.7 | 36.7 | 22.8 | 122.8 | 6191.0 |
| 1958 | 3944.4 | 1540.6 | 950.0 | 322.3 | 38.3 | 24.3 | 132.4 | 6639.0 |
| 1959 | 4250.8 | 1730.5 | 1047.6 | 348.4 | 40.6 | 25.0 | 142.7 | 7250.3 |
| 1960 | 4547.4 | 1880.0 | 1116.4 | 370.4 | 43.9 | 37.7 | 156.1 | 7764.3 |
| 1961 | 4797.5 | 2046.7 | 1170.6 | 393.0 | 47.1 | 40.5 | 164.5 | 8249.9 |
| 1962 | 5088.5 | 2250.4 | 1221.4 | 408.4 | 50.2 | 38.7 | 167.4 | 8812.8 |
| 1963 | 5389.7 | 2442.3 | 1294.8 | 430.3 | 55.4 | 43.8 | 178.0 | 9390.9 |
| 1964 | 5633.7 | 2709.3 | 1496.2 | 455.5 | 56.0 | 44.7 | 194.8 | 10111.1 |
| 1965 | 5961.3 | 2988.2 | 1625.5 | 478.3 | 59.6 | 51.1 | 208.4 | 10853.4 |
| 1966 | 6354.7 | 3471.2 | 1803.2 | 504.1 | 68.4 | 63.4 | 230.1 | 11908.2 |
| 1967 | 6737.7 | 3815.3 | 1922.6 | 533.5 | 75.4 | 75.4 | 248.5 | 12760.6 |
| 1968 | 7184.1 | 4201.4 | 2139.7 | 567.7 | 81.1 | 74.0 | 290.0 | 13816.1 |
| 1969 | 7774.4 | 4884.6 | 2413.3 | 615.6 | 90.2 | 94.3 | 330.5 | 15353.2 |
| 1970 | 8456.0 | 5179.6 | 2694.5 | 677.9 | 86.9 | 140.0 | 385.5 | 16569.4 |
| 1971 | 9187.0 | 5716.9 | 2933.1 | 713.9 | 114.2 | 154.3 | 430.1 | 18080.7 |
| 1972 | 10362.0 | 6323.5 | 3447.2 | 766.4 | 127.3 | 138.9 | 489.9 | 20397.6 |
| 1973 | 11417.6 | 7269.8 | 4007.8 | 831.2 | 136.0 | 152.4 | 548.5 | 22061.5 |
| 1974 | 12811.8 | 7923.5 | 4536.3 | 912.8 | 158.8 | 191.2 | 609.5 | 25542.5 |
| 1975 | 14026.8 | 8849.4 | 5074.6 | 1008.2 | 182.3 | 214.6 | 673.4 | 28253.2 |
| 1976 | 15607.8 | 10049.1 | 6014.9 | 1141.8 | 200.6 | 226.6 | 763.2 | 32024.4 |
| 1977 | 17069.6 | 11206.7 | 6885.5 | 1314.8 | 229.6 | 262.0 | 844.9 | 35599.3 |
| 1978 | 18743.7 | 12820.3 | 7948.3 | 1531.2 | 300.1 | 342.2 | 945.7 | 40055.6 |
| 1979 | 20271.8 | 14506.6 | 8849.1 | 1810.0 | 409.3 | 459.7 | 965.9 | 44421.2 |

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## Table 2

## Output Price and Quantity Indexes

### (millions of 1967 dollars)

| Year | Local Revenues | | Toll: Interstate Revenues | | Toll: Intrastate Revenues | | Directory Advertising | | Miscellaneous Revenues | |
|------|---------------|-------------|---------------------------|-------------|---------------------------|-------------|-----------------------|-------------|------------------------|-------------|
| | Quantity Index | Price Index | Quantity Index | Price Index | Quantity Index | Price Index | Quantity Index | Price Index | Quantity Index | Price Index |
| 1947 | 1822.7 | .683 | 516.1 | .995 | 457.1 | .830 | 206.6 | .389 | 21.1 | .631 |
| 1948 | 2046.0 | .721 | 570.1 | .995 | 475.5 | .886 | 236.2 | .419 | 23.4 | .675 |
| 1949 | 2179.0 | .762 | 574.5 | .994 | 503.3 | .948 | 254.2 | .449 | 26.0 | .667 |
| 1950 | 2338.8 | .812 | 652.6 | .995 | 521.2 | .978 | 256.9 | .479 | 27.7 | .681 |
| 1951 | 2503.9 | .839 | 772.1 | .994 | 550.0 | .992 | 277.5 | .488 | 28.6 | .727 |
| 1952 | 2662.1 | .881 | 848.9 | 1.008 | 578.4 | 1.008 | 314.3 | .498 | 30.5 | .736 |
| 1953 | 2817.6 | .917 | 901.9 | 1.031 | 588.1 | 1.030 | 326.7 | .568 | 32.7 | .747 |
| 1954 | 2962.4 | .936 | 943.4 | 1.088 | 626.6 | 1.046 | 351.2 | .598 | 34.4 | .757 |
| 1955 | 3184.6 | .948 | 1078.5 | 1.089 | 702.4 | 1.058 | 364.7 | .630 | 38.3 | .774 |
| 1956 | 3440.7 | .957 | 1208.3 | 1.088 | 767.8 | 1.059 | 388.3 | .665 | 40.6 | .798 |
| 1957 | 3671.4 | .971 | 1318.2 | 1.087 | 826.7 | 1.053 | 399.0 | .722 | 43.4 | .824 |
| 1958 | 3855.2 | 1.000 | 1387.1 | 1.085 | 866.4 | 1.071 | 416.0 | .757 | 44.6 | .837 |
| 1959 | 4125.2 | 1.007 | 1571.7 | 1.081 | 945.9 | 1.083 | 427.9 | .778 | 46.3 | .856 |
| 1960 | 4403.7 | 1.007 | 1735.5 | 1.057 | 1002.8 | 1.086 | 443.4 | .815 | 49.2 | .869 |
| 1961 | 4636.7 | 1.010 | 1809.8 | 1.057 | 1046.1 | 1.092 | 451.5 | .849 | 52.4 | .877 |
| 1962 | 4913.7 | 1.012 | 2077.9 | 1.058 | 1110.5 | 1.075 | 454.6 | .878 | 54.9 | .895 |
| 1963 | 5200.8 | 1.012 | 2276.4 | 1.048 | 1195.7 | 1.058 | 459.6 | .878 | 54.9 | .895 |
| 1964 | 5439.8 | 1.012 | 2534.0 | 1.044 | 1386.1 | 1.054 | 459.6 | .915 | 59.7 | .908 |
| 1965 | 5791.2 | 1.005 | 2876.1 | 1.015 | 1541.2 | 1.030 | 475.1 | .936 | 59.3 | .922 |
| 1966 | 6184.0 | 1.003 | 3356.7 | 1.009 | 1737.1 | 1.013 | 487.2 | .959 | 61.8 | .942 |
| 1967 | 6570.9 | 1.000 | 3720.9 | 1.000 | 1875.0 | 1.000 | 502.0 | .980 | 68.7 | .972 |
| 1968 | 6990.8 | 1.001 | 4185.1 | .978 | 2094.5 | .995 | 520.3 | 1.000 | 73.6 | 1.000 |
| 1969 | 7481.5 | 1.011 | 4834.8 | .983 | 2358.6 | .996 | 539.1 | 1.026 | 75.7 | 1.044 |
| 1970 | 7896.6 | 1.038 | 5291.4 | .949 | 2554.5 | .996 | 543.9 | 1.101 | 80.1 | 1.095 |
| 1971 | 8241.2 | 1.080 | 5679.5 | .975 | 2554.5 | 1.022 | 566.1 | 1.161 | 73.3 | 1.149 |
| 1972 | 8715.2 | 1.153 | 6250.3 | .981 | 2683.3 | 1.059 | 578.2 | 1.196 | 91.7 | 1.207 |
| 1973 | 9258.6 | 1.197 | 7064.5 | .999 | 2995.0 | 1.117 | 607.4 | 1.224 | 98.1 | 1.259 |
| 1974 | 9752.1 | 1.274 | 7698.9 | .998 | 3332.2 | 1.167 | 643.3 | 1.254 | 99.1 | 1.332 |
| 1975 | 10105.1 | 1.346 | 8288.1 | 1.035 | 3642.3 | 1.208 | 661.3 | 1.338 | 105.1 | 1.465 |
| 1976 | 10604.0 | 1.428 | 9196.8 | 1.060 | 3901.2 | 1.261 | 667.8 | 1.464 | 110.4 | 1.601 |
| 1977 | 11208.5 | 1.477 | 10208.7 | 1.065 | 4263.3 | 1.369 | 692.5 | 1.599 | 115.6 | 1.684 |
| 1978 | 11877.7 | 1.529 | 11630.6 | 1.068 | 4723.6 | 1.414 | 721.7 | 1.767 | 125.4 | 1.776 |
| 1979 | 12536.4 | 1.567 | 13221.9 | 1.063 | 5316.6 | 1.448 | 761.9 | 1.947 | 152.1 | 1.912 |
| | | | | | 5862.8 | 1.457 | 820.3 | 2.138 | 190.6 | 2.080 |

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Table 3


Aggregate
Output
(millions of 1967 dollars)


| Year | Quantity Index | Price Index |
|------|----------------|-------------|
| 1947 | 2995.2 | .745 |
| 1948 | 3309.7 | .779 |
| 1949 | 3483.0 | .815 |
| 1950 | 3750.1 | .853 |
| 1951 | 4091.0 | .873 |
| 1952 | 4384.6 | .964 |
| 1953 | 4614.8 | .938 |
| 1954 | 4860.3 | .965 |
| 1955 | 5321.1 | .977 |
| 1956 | 5802.0 | .984 |
| 1957 | 6220.0 | .995 |
| 1958 | 6529.8 | 1.017 |
| 1959 | 7085.6 | 1.023 |
| 1960 | 7606.3 | 1.021 |
| 1961 | 8050.9 | 1.025 |
| 1962 | 8590.9 | 1.026 |
| 1963 | 9175.8 | 1.023 |
| 1964 | 9885.9 | 1.023 |
| 1965 | 10754.0 | 1.009 |
| 1966 | 11847.9 | 1.005 |
| 1967 | 12760.6 | 1.000 |
| 1968 | 13882.9 | .995 |
| 1969 | 15287.1 | 1.004 |
| 1970 | 16359.3 | 1.013 |
| 1971 | 17240.2 | 1.049 |
| 1972 | 18611.0 | 1.096 |
| 1973 | 20294.9 | 1.131 |
| 1974 | 21718.9 | 1.176 |
| 1975 | 22878.6 | 1.235 |
| 1976 | 24585.8 | 1.303 |
| 1977 | 26599.6 | 1.338 |
| 1978 | 29177.2 | 1.373 |
| 1979 | 31876.7 | 1.394 |

Table 4

Revenue Shares by Type of Output

| Year | Local | Toll: Interstate | Toll: Intrastate | Directory Advertising | Miscellaneous Revenue |
|------|-------|------------------|------------------|----------------------|----------------------|
| 1947 | .558 | .236 | .170 | .036 | .006 |
| 1948 | .572 | .220 | .163 | .038 | .006 |
| 1949 | .585 | .201 | .168 | .040 | .006 |
| 1950 | .594 | .203 | .159 | .038 | .006 |
| 1951 | .588 | .215 | .153 | .038 | .006 |
| 1952 | .592 | .216 | .147 | .039 | .006 |
| 1953 | .597 | .215 | .140 | .043 | .006 |
| 1954 | .591 | .219 | .140 | .045 | .006 |
| 1955 | .581 | .226 | .143 | .044 | .006 |
| 1956 | .577 | .230 | .142 | .045 | .006 |
| 1957 | .576 | .231 | .141 | .047 | .006 |
| 1958 | .580 | .227 | .140 | .047 | .006 |
| 1959 | .573 | .234 | .141 | .046 | .005 |
| 1960 | .571 | .236 | .140 | .047 | .006 |
| 1961 | .567 | .242 | .138 | .046 | .006 |
| 1962 | .564 | .250 | .135 | .045 | .006 |
| 1963 | .561 | .254 | .135 | .045 | .006 |
| 1964 | .544 | .262 | .145 | .044 | .005 |
| 1965 | .536 | .269 | .146 | .043 | .005 |
| 1966 | .521 | .284 | .148 | .041 | .006 |
| 1967 | .515 | .292 | .147 | .041 | .006 |
| 1968 | .507 | .296 | .151 | .040 | .006 |
| 1969 | .493 | .310 | .153 | .039 | .006 |
| 1970 | .495 | .303 | .158 | .040 | .005 |
| 1971 | .492 | .306 | .157 | .038 | .006 |
| 1972 | .493 | .301 | .164 | .036 | .006 |
| 1973 | .483 | .307 | .169 | .035 | .006 |
| 1974 | .486 | .301 | .172 | .035 | .006 |
| 1975 | .481 | .304 | .174 | .035 | .006 |
| 1976 | .473 | .304 | .182 | .035 | .006 |
| 1977 | .465 | .305 | .188 | .036 | .006 |
| 1978 | .453 | .310 | .192 | .037 | .007 |
| 1979 | .442 | .316 | .193 | .039 | .009 |

Average Shares

| | Local | Toll: Interstate | Toll: Intrastate | Directory Advertising | Miscellaneous |
|------|-------|------------------|------------------|----------------------|---------------|
| 1947-61 | .580 | .223 | .148 | .043 | .006 |
| 1961-79 | .504 | .290 | .160 | .039 | .006 |
| 1947-79 | .537 | .261 | .156 | .041 | .006 |

## Table 5

### Rates of Growth of Output

| Year | Local | Toll: Interstate | Toll: Intrastate | Directory Advertising | Miscellaneous Revenues | Aggregate Output |
|------|-------|------------------|------------------|-----------------------|------------------------|------------------|
| 1948 | .116 | .100 | .040 | .133 | .102 | .100 |
| 1949 | .063 | .008 | .057 | .074 | .107 | .051 |
| 1950 | .071 | .127 | .035 | .010 | .063 | .074 |
| 1951 | .068 | .168 | .054 | .077 | .031 | .087 |
| 1952 | .061 | .095 | .050 | .125 | .065 | .069 |
| 1953 | .057 | .061 | .017 | .039 | .065 | .069 |
| 1954 | .050 | .045 | .063 | .072 | .050 | .051 |
| 1955 | .072 | .134 | .114 | .037 | .100 | .052 |
| 1956 | .077 | .114 | .089 | .063 | .058 | .091 |
| 1957 | .065 | .087 | .074 | .027 | .060 | .087 |
| 1958 | .049 | .051 | .047 | .042 | .027 | .070 |
| 1959 | .068 | .125 | .088 | .028 | .037 | .049 |
| 1960 | .065 | .099 | .050 | .035 | .061 | .062 |
| 1961 | .052 | .085 | .042 | .018 | .062 | .071 |
| 1962 | .058 | .095 | .060 | .007 | .047 | .057 |
| 1963 | .057 | .091 | .074 | .011 | .004 | .065 |
| 1964 | .045 | .107 | .148 | .033 | -.006 | .075 |
| 1965 | .063 | .127 | .106 | .025 | .041 | .084 |
| 1966 | .066 | .155 | .120 | .030 | .106 | .097 |
| 1967 | .061 | .103 | .076 | .036 | .068 | .074 |
| 1968 | .062 | .118 | .111 | .035 | .029 | .084 |
| 1969 | .068 | .144 | .119 | .009 | .057 | .096 |
| 1970 | .054 | .090 | .080 | .040 | -.009 | .068 |
| 1971 | .043 | .071 | .049 | .021 | .224 | .052 |
| 1972 | .056 | .096 | .110 | .049 | .068 | .077 |
| 1973 | .060 | .122 | .107 | .057 | .010 | .087 |
| 1974 | .052 | .086 | .089 | .028 | .059 | .068 |
| 1975 | .036 | .074 | .069 | .010 | .049 | .052 |
| 1976 | .048 | .104 | .089 | .036 | .046 | .072 |
| 1977 | .055 | .104 | .103 | .041 | .061 | .079 |
| 1978 | .058 | .130 | .118 | .054 | .193 | .092 |
| 1979 | .054 | .128 | .101 | .074 | .226 | .088 |

| | Local | Toll: Interstate | Toll: Intrastate | Directory Advertising | Miscellaneous | Total Output |
|------|-------|------------------|------------------|-----------------------|---------------|--------------|
| 1947-61 | .067 | .093 | .059 | .056 | .065 | .071 |
| 1961-79 | .058 | .108 | .096 | .033 | .072 | .076 |
| 1947-79 | .060 | .101 | .080 | .043 | .069 | .074 |

# 4. MEASUREMENT OF LABOR INPUT

The value of labor input encompasses all labor related payments including wages, fringe benefits, employer social security payments, and unemployment insurance. The resulting value of labor input, which we refer to as total compensation, is given in the first column of Table 6.

To construct a quantity index for labor input we start with data on hours worked by non-construction employees in the Bell System. Construction employees are excluded since their input is included in the capital input they produce. As will be discussed in Section 5, capital input includes not only that purchased from outside sources but also that produced within the Bell System.

The data on hours of non-construction employees are broken down by occupation and years of service. For 1973 to 1979, the data are also classified by age. Table 7a indicates the breakdown by occupation and years of service, showing the number of hours worked by each group in specified years. Table 7b shows the breakdown by occupation, years of service, and age and the number of hours worked by each group in 1979.

We aggregate hours worked in the various labor groups using the Tornqvist index procedure. Denoting the index of hours worked by L and the wage index by $P_L$, we represent the value of labor input as the sum of the values of labor input from the various categories:

$$P_L L = \Sigma \ P_{Lj} \ L_j,$$

where $P_{Lj}$ is the price of the $j^{\text{th}}$ type of labor, and $L_j$ is the number of hours worked by employees of this type. The Tornqvist index of hours worked L is related to the $L_j$ as follows:

Table 6

Labor Input

| Year | Total Compensation (millions of dollars) | Hours Worked (millions) | Compensation Index | Quantity Index (millions of 1967 dollars) | Price Index |
|------|-------------|--------|------|--------|--------|
| 1947 | 1266.6 | 825.7 | .859 | 3065.5 | .413 |
| 1948 | 1445.7 | 859.3 | .867 | 3220.8 | .449 |
| 1949 | 1551.0 | 856.0 | .891 | 3299.0 | .470 |
| 1950 | 1615.2 | 834.7 | .919 | 3318.3 | .487 |
| 1951 | 1789.8 | 877.6 | .914 | 3469.1 | .516 |
| 1952 | 1993.1 | 918.1 | .918 | 3642.3 | .547 |
| 1953 | 2152.6 | 947.2 | .929 | 3802.9 | .566 |
| 1954 | 2252.7 | 941.9 | .943 | 3840.3 | .587 |
| 1955 | 2388.4 | 937.0 | .948 | 3842.1 | .622 |
| 1956 | 2587.4 | 1015.0 | .944 | 4141.0 | .625 |
| 1957 | 2628.8 | 983.3 | .945 | 4017.1 | .654 |
| 1958 | 2635.6 | 957.0 | .972 | 4020.2 | .656 |
| 1959 | 2739.3 | 966.1 | .992 | 3861.0 | .709 |
| 1960 | 2855.1 | 893.6 | .999 | 3858.2 | .740 |
| 1961 | 2948.6 | 877.0 | 1.008 | 3822.5 | .771 |
| 1962 | 3064.7 | 876.6 | 1.011 | 3833.9 | .799 |
| 1963 | 3169.6 | 871.4 | 1.016 | 3830.0 | .828 |
| 1964 | 3439.3 | 899.9 | 1.015 | 3950.3 | .871 |
| 1965 | 3689.9 | 936.4 | 1.009 | 4086.3 | .903 |
| 1966 | 4027.8 | 983.0 | 1.001 | 4253.8 | .947 |
| 1967 | 4329.1 | 1001.2 | 1.000 | 4329.1 | 1.000 |
| 1968 | 4613.9 | 1019.4 | .998 | 4399.3 | 1.049 |
| 1969 | 5351.1 | 1067.4 | .988 | 4643.3 | 1.152 |
| 1970 | 6123.2 | 1147.2 | .986 | 4889.6 | 1.252 |
| 1971 | 6877.1 | 1143.2 | 1.000 | 4943.5 | 1.391 |
| 1972 | 7876.3 | 1123.4 | 1.020 | 4953.0 | 1.590 |
| 1973 | 8787.0 | 1133.3 | 1.019 | 5035.7 | 1.745 |
| 1974 | 9844.5 | 1144.0 | 1.026 | 5073.8 | 1.940 |
| 1975 | 11114.7 | 1114.8 | 1.048 | 5050.7 | 2.201 |
| 1976 | 12369.3 | 1084.6 | 1.063 | 4983.1 | 2.482 |
| 1977 | 13641.1 | 1106.4 | 1.085 | 5192.5 | 2.627 |
| 1978 | 15347.8 | 1154.2 | 1.086 | 5419.7 | 2.832 |
| 1979 | 17587.4 | 1207.7 | 1.079 | 5636.3 | 3.120 |

Table 7a

Hours Worked by Occupation and Years of Service
(millions of hours)

Telephone Operators

|  | -1 yr. | 1-2 yrs. | 3-5 yrs. | 6+ yrs. |  |
|------|------|------|------|------|------|
| 1950 | 46.3 | 85.8 | 106.4 | 117.0 | 1950 |
| 1960 | 39.3 | 38.0 | 48.6 | 163.9 | 1960 |
| 1970 | 88.1 | 73.3 | 37.5 | 103.8 | 1979 |
| 1979 | 35.4 | 28.1 | 16.6 | 82.3 | 1979 |

Plant Craftsman

|  | -1 yr. | 1-2 yrs. | 3-5 yrs. | 6+ yrs. |  |
|------|------|------|------|------|------|
| 1950 | 7.3 | 31.9 | 43.7 | 69.3 | 1950 |
| 1960 | 4.3 | 8.8 | 47.4 | 129.8 | 1960 |
| 1970 | 42.6 | 46.0 | 45.2 | 149.2 | 1970 |
| 1979 | 14.1 | 13.4 | 18.4 | 228.3 | 1979 |

Clerical

|  | -1 yr. | 1-2 yrs. | 3-5 yrs. | 6+ yrs. |  |
|------|------|------|------|------|------|
| 1950 | 17.7 | 37.8 | 38.2 | 50.5 | 1950 |
| 1960 | 25.6 | 25.8 | 35.7 | 83.8 | 1960 |
| 1970 | 47.7 | 47.4 | 32.0 | 83.1 | 1970 |
| 1979 | 28.1 | 28.5 | 24.8 | 121.0 | 1979 |

Other Non-Supervisory

|  | -1 yr. | 1-2 yrs. | 3-5 yrs. | 6+ yrs. |  |
|------|------|------|------|------|------|
| 1950 | 6.4 | 16.2 | 19.6 | 25.0 | 1950 |
| 1960 | 8.8 | 11.0 | 19.8 | 48.5 | 1960 |
| 1970 | 27.1 | 25.9 | 18.0 | 47.9 | 1970 |
| 1979 | 28.4 | 30.3 | 29.1 | 145.8 | 1979 |

Table 7a (continued)

## *Foreman and Supervisors

|      | -5 yrs. | 5-9 yrs. | 10+ yrs. |      |
|------|---------|----------|----------|------|
| 1950 | 3.9     | 7.7      | 60.6     | 1950 |
| 1960 | 2.0     | 6.5      | 79.1     | 1960 |
| 1970 | 8.9     | 11.4     | 88.5     | 1970 |
| 1979 | 8.4     | 22.6     | 109.7    | 1979 |

## *Executive and Staff

|      | -5 yrs. | 5-9 yrs. | 10+ yrs. |      |
|------|---------|----------|----------|------|
| 1950 | 5.5     | 3.3      | 34.6     | 1950 |
| 1960 | 4.6     | 7.1      | 55.2     | 1960 |
| 1970 | 19.3    | 12.0     | 92.3     | 1970 |
| 1979 | 27.2    | 36.4     | 130.8    | 1979 |

*Prior to 1965, hours worked by each of these occupation and years of service classes are available, but wage rates are not. "Foremen and Supervisors" and "Executive and Staff" are combined into "All Management." Wage rates for "All Management" are available prior to 1965 for the years of service classes 0-5 years, 5-9 years, and 10+ years.

## Table 7b

### 1979 Hours Worked by Occupation, Years of Service, and Age

(millions of hours)

| | Age | | | | |
|---|---|---|---|---|---|
| | 0-24 | 25-34 | 35-44 | 45-54 ! | 55 + |
| **Telephone Operators** | | | | | |
| -1 yr. | 21.5 | 9.8 | 2.6 | 1.2 | .2 |
| 1-2 yrs. | 13.2 | 9.5 | 3.2 | 1.8 | .3 |
| 3-5 yrs. | 5.5 | 7.7 | 1.8 | 1.3 | .3 |
| 6+ yrs. | 1.0 | 26.0 | 16.5 | 25.3 | 13.5 |
| **Plant Craftsman** | | | | | |
| -1 yr. | 6.5 | 6.0 | 1.1 | .4 | .1 |
| 1-2 yrs. | 5.3 | 6.5 | 1.2 | .4 | .1 |
| 3-5 yrs. | 4.5 | 12.2 | 1.3 | .4 | .1 |
| 6+ yrs. | 1.2 | 93.6 | 56.8 | 53.5 | 23.2 |
| **Clerical** | | | | | |
| -1 yr. | 13.6 | 9.2 | 3.3 | 1.6 | .3 |
| 1-2 yrs. | 11.6 | 10.9 | 3.7 | 1.8 | .4 |
| 3-5 yrs. | 8.0 | 12.3 | 2.7 | 1.4 | .4 |
| 6+ yrs. | 2.3 | 53.5 | 25.3 | 27.1 | 12.8 |
| **Other Non-Supervisory** | | | | | |
| -1 yr. | 12.6 | 12.2 | 2.5 | .9 | .2 |
| 1-2 yrs. | 10.7 | 14.6 | 3.3 | 1.4 | .3 |
| 3-5 yrs. | 8.1 | 16.2 | 3.0 | 1.4 | .4 |
| 6+ yrs. | 2.3 | 63.5 | 29.7 | 32.5 | 17.8 |
| **Foremen & Supervisors** | | | | | |
| -5 yrs. | 1.8 | 5.0 | 1.1 | .4 | .1 |
| 5-9 yrs. | .7 | 17.8 | 3.2 | .8 | .2 |
| 10+ yrs. | .0 | 17.6 | 33.5 | 41.7 | 16.9 |
| **Executive & Staff** | | | | | |
| -5 yrs. | 6.2 | 16.3 | 3.6 | .9 | .2 |
| 5-9 yrs. | 1.2 | 27.3 | 6.0 | 1.5 | .4 |
| 10+ yrs. | .0 | 20.2 | 39.8 | 46.8 | 23.9 |

$$\text{ln } L(T) - \text{ln } L(T-1) = \sum_j \bar{v}_{jt} \{ \text{ln } L_j (T) - \text{ln } L_j (T-1) \}$$

where the weights ($\bar{v}_j$) are the average shares of each type of labor in the value of total labor input. Therefore, in addition to hours worked we need data on the weights to construct the labor quantity index. Although we have data on wage payments to each type of labor, we do not have information on payments of fringe benefits, social security, etc., to each type of labor. We believe it is a reasonable approximation of reality to assume that non-wage compensation is proportional to wage compensation. Thus we have used the wage payment shares as estimates of the total compensation shares in the aggregation procedure.

Average hourly wages used to create the wage shares were available for the categories specified in Tables 7a and 7b. As Table 7a indicates, we could not obtain a breakdown of "management" wages into "foremen and supervisors" and "executive and staff" wages before 1965. We therefore used the "all management" wage rate to aggregate hours worked by "foremen and supervisors" and "executive and staff" in the early period.

The resulting aggregate labor quantity index is scaled to equal labor compensation in our base year, 1967. The ratio between this index and total hours worked provides an index of labor input per hour work, which reflects changes over time in the composition of the Bell System work force.

The price and quantity indexes of labor input are presented in Table 6, along with total compensation, hours worked, and the index of labor input per hour worked. From 1947 to 1956 the quantity index grew at a rate of 3.3% per year. This is due to an increase in both hours worked and composition of the work force. The increase in the composition index results from changes in both the occupational mix and the experience level of the Bell employees. Between 1956 and 1963 there